

Study of Hadronic and Rare B Decays in BABAR

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Abstract

We present results from BABAR experiment for the measurement of inclusive and exclusive branching fractions of B mesons into final states containing J/ψ , $\psi(2S)$ and χ_c . The contributions of CP even and odd amplitudes in the decay $B^0 \rightarrow J/\psi K^{*0}$ are determined from an angular analysis. We report the measurements of the branching ratios $B^0 \rightarrow D^{*+} D^{*-}$ and $D^{*+} D^{*-} K_S^0$, and the study of exclusive two-body and quasi-two-body charmless decays. The branching fraction of the decay $B^0 \rightarrow K^{*0} \gamma$ has been determined and the corresponding CP asymmetry has been measured.

Contributed to the Proceedings of the International Conference on Flavor Physics (ICFP 2001)
31 May - 6 Jun 2001, Zhang-Jia-Jie City, Hunan, China

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Work supported in part by Department of Energy contract DE-AC03-76SF00515.

1 PEP-II and BABAR detector

The PEP-II asymmetric B-factory collides electrons with 9 GeV energy and positrons with 3.1 GeV energy. The center-of-mass energy corresponds to the $\Upsilon(4S)$ resonance, which is produced with a Lorentz boost of $\beta\gamma = 0.56$ in the laboratory frame. The peak luminosity reached in the running period from November 1999 to October 2000 was $3.3 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$. The integrated luminosity in that period is approximately 21 fb^{-1} . An additional 4 fb^{-1} have been collected below the resonance, in order to study the non-resonant $e^+e^- \rightarrow q\bar{q}$ background.

The BABAR detector [1] consists of a five-layer double-sided Silicon Vertex Tracker (SVT), a Drift Chamber (DCH) with 40 layer, a Cherenkov radiation detector (DIRC: Detector of Internally Reflected Cherenkov light) [2], a finely-segmented CsI(Tl) Electromagnetic Calorimeter (EMC) and a muon and neutral hadron detector (IFR: Instrumented Flux Return) consisting of Resistive Plate Chambers (RPC) incorporated in the flux return of the 1.5 T magnetic field produced by a solenoidal superconducting magnet.

2 B counting

The determination of the branching fractions of B decays requires a correct estimate of the number of produced $\Upsilon(4S) \rightarrow BB$ events. The number of BB events, N_{BB} , is estimated from a selection of multihadronic decays, after subtracting the expected number of events from continuum, which is determined from PEP-II runs taken at a center-of-mass energy below the $\Upsilon(4S)$ resonance, scaled according to the number of selected dimuon events recorded in on- and off-resonance data. The number of BB events is:

$$N_{BB} = N_{MH} - N_{MH}^{off} \frac{N_{\mu\mu}}{N_{\mu\mu}^{off}} \kappa, \quad (1)$$

where N_{MH} is the number of multihadronic events taken in on-resonance runs, N_{MH}^{off} is the number of multihadron events selected off-resonance, $N_{\mu\mu}$ and $N_{\mu\mu}^{off}$ are the number of selected dimuon events in on- and off-resonance data respectively. The term $\kappa = 0.9962 \pm 0.0027$ corrects for the different efficiencies at different center-of-mass energies for dimuon and multihadronic events. The number of produced $\Upsilon(4S) \rightarrow BB$ decays for the analyses that are presented in this paper is $(22.6 \pm 0.4) \times 10^6$ events.

3 Charmonium decays

Many B decays containing charmonium final states are important for CP violation studies and the determination of $\sin 2\beta$. Moreover, the precise determination of many inclusive and exclusive branching fractions can be used for a test of theoretical predictions based on the factorization hypothesis.

J/ψ , $\psi(2S)$ and χ_c candidates are reconstructed in final states containing leptons. J/ψ candidates are reconstructed in decays to $\ell^+\ell^-$ ($\ell = e$ or μ), $\psi(2S)$ candidates are reconstructed both in $\ell^+\ell^-$ and $J/\psi\pi^+\pi^-$ decay modes, and χ_c candidates are reconstructed in the decay mode $J/\psi\gamma$. Details of the performance of BABAR for muon and electron identification and photon energy measurement can be found in the Ref. [1].

In the case of final states containing electrons, a bremsstrahlung recovery algorithm is applied: final state radiation photons that might have been radiated from electrons coming from charmonium decays are identified and considered in the calculation of the final state kinematics.

3.1 Inclusive Charmonium decays

The inclusive branching ratios of B decays to charmonium final states are obtained from the fit to the number of events under the peaks of charmonium resonances, correct for particle identification and reconstruction efficiencies (estimated from control samples extracted from real data), normalized to the number of produced BB events estimated with the B -counting procedure described in the previous section.

Inclusive branching fractions for direct decays of $B \rightarrow J/\psi X$ and $B \rightarrow \chi_{c1} X$ are obtained subtracting the contribution expected from the decay $B \rightarrow \psi(2S)X$ followed by a decay of the $\psi(2S)$ in J/ψ and χ_{c1} , respectively. The branching fractions for $\psi(2S)$ to decay to J/ψ and χ_{c1} are assumed to be the PDG values. We determine the inclusive branching fractions shown in Table 1. The χ_c analysis shows evident for χ_{c1} resonance, with a shoulder that could be interpreted as χ_{c2} . The branching fraction for $B \rightarrow \chi_{c2} X$ is determined to be $0.137 \pm 0.058 \pm 0.012$, but given the low statistical significance, we prefer to quote the upper limit $Br(B \rightarrow \chi_{c2} X) < 0.21 \times 10^{-2}$ (90%) C.L.

Table 1: Measured inclusive branching fraction for B to decay to charmonium final states. The last two measurement refer to inclusive branching fractions for direct decay.

Decay Mode	Branching Fraction
$B \rightarrow J/\psi X$	$(1.044 \pm 0.013 \pm 0.028) \times 10^{-2}$
$B \rightarrow \psi(2S)X$	$(0.275 \pm 0.020 \pm 0.029) \times 10^{-2}$
$B \rightarrow \chi_{c1} X$	$(0.378 \pm 0.034 \pm 0.026) \times 10^{-2}$
$B \rightarrow \chi_{c2} X$	$< 0.21 \times 10^{-2}$, 90% C.L.
$B \rightarrow J/\psi X (dir.)$	$(0.789 \pm 0.010 \pm 0.034) \times 10^{-2}$
$B \rightarrow \chi_{c1} X (dir.)$	$(0.353 \pm 0.034 \pm 0.024) \times 10^{-2}$

As a byproduct of this analysis, we determine the branching fractions for $\psi(2S) \rightarrow e^+e^-$ and $\psi(2S) \rightarrow \mu^+\mu^-$ from the ratio of branching fractions for $B \rightarrow \psi(2S)X \rightarrow e^+e^-X$ and $B \rightarrow \psi(2S)X \rightarrow \mu^+\mu^-X$ to $B \rightarrow \psi(2S)X \rightarrow J/\psi\pi^+\pi^-X$, assuming the PDG value for the branching ratio $\psi(2S) \rightarrow J/\psi\pi^+\pi^-$.

The results are

$$\begin{aligned} \mathcal{B}(\psi(2S) \rightarrow e^+e^-) &= (8.1 \pm 0.9 \pm 0.9) \times 10^{-3}, \\ \mathcal{B}(\psi(2S) \rightarrow \mu^+\mu^-) &= (7.0 \pm 0.8 \pm 0.9) \times 10^{-3}. \end{aligned}$$

The $\psi(2S) \rightarrow \mu^+\mu^-$ measurement significantly improves the precision of the current world average.

3.2 Charmonium production in continuum

The sample of J/ψ candidates shows evidence for events in which the momentum of the J/ψ is larger than 2 GeV in the $\Upsilon(4S)$ rest frame, which is kinematically forbidden for B decays. The observed number of events is consistent with observed number of J/ψ candidates in the data taken below the $\Upsilon(4S)$ resonance energy [5]. Those events are interpreted as J/ψ production in continuum.

We determine a production cross section of $\sigma_{e^+e^- \rightarrow J/\psi X} = (2.52 \pm 0.21 \pm 0.21)$ pb and the direct production from $\Upsilon(4S)$ is excluded: $\mathcal{B}(\Upsilon(4S) \rightarrow J/\psi X) < 4.3 \times 10^{-4}, 90\%$ C.L.. The measured cross section together with the observed angular distribution of the J/ψ [5], favours the non-relativistic QCD [3] models over color-singlet models [4].

The (small) contribution from J/ψ production in continuum events has been subtracted from the estimates of inclusive charmonium branching fractions reported in Table 1.

3.3 Exclusive Charmonium decays

The kinematic selection of exclusive B decays is based on two main variables that provide an effective background discrimination.

- The energy substituted mass:

$$m_{ES} = \sqrt{\frac{s}{4} - p_{B,cm}^2},$$

where s is the PEP-II center-of-mass energy squared, and $p_{B,cm}$ is the measured B momentum in the $\Upsilon(4S)$ rest frame. In the calculation of m_{ES} there is no assumption on the mass of the particles in the B final state, so m_{ES} doesn't depend on particle identification.

- Energy difference:

$$\Delta E = E_{B,cm} - \frac{\sqrt{s}}{2}$$

where $E_{B,cm}$ is the measured B energy in the $\Upsilon(4S)$ rest frame. The ΔE distribution peaks around 0 for correctly reconstructed B decays.

In the decay $B^0 \rightarrow J/\psi K_L^0$ the K_L^0 is reconstructed as a cluster in the IFR and/or in the EMC, so its direction is measured, but no energy determination is possible. Therefore, only the variable ΔE is determined, assuming the mass constraint $m_{ES} = m_B$ to determine the momentum of the K_L .

We measure [6] the branching fractions summarised in Table 2. We report the first observation of $B^0 \rightarrow \chi_{c1} K^{0*}$.

Using an unbinned maximum likelihood fit based on kinematic variables, we also determine [7] the ratio of branching fractions for the decays $B^+ \rightarrow J/\psi \pi^+$ and $B^+ \rightarrow J/\psi K^+$ to be

$$\frac{\mathcal{B}(B^+ \rightarrow J/\psi \pi^+)}{\mathcal{B}(B^+ \rightarrow J/\psi K^+)} = (3.91 \pm 0.78 \pm 0.19) \times 10^{-2}.$$

3.4 $J/\psi K^{*0}$ angular analysis

The decay $B^0 \rightarrow J/\psi K^{*0}$ contains a mixture of CP -odd and CP -even amplitudes. It is possible to interpret CP -violation asymmetries in this channel by disentangling the two CP components with an angular analysis of the decay products.

The decay can be characterized by three amplitudes A_{\parallel} , A_0 and A_{\perp} (defined in the Ref. [8]), which correspond to the CP -odd P-wave (A_{\perp}) and CP -even mixtures of S and D waves (A_0 and A_{\parallel}). The squared moduli of the three amplitudes and their relative phases can be determined from a fit to the angular distribution of the decay products.

Table 2: Branching fraction for B decays to exclusive charmonium final states.

Decay Mode	Branching Fraction
$B^0 \rightarrow J/\psi \pi^0$	$(0.20 \pm 0.06 \pm 0.02) \times 10^{-4}$
$B^0 \rightarrow J/\psi K^{*0}$	$(12.4 \pm 0.5 \pm 0.9) \times 10^{-4}$
$B^+ \rightarrow J/\psi K^{*+}$	$(13.7 \pm 0.9 \pm 1.1) \times 10^{-4}$
$B^+ \rightarrow J/\psi K^+$	$(10.1 \pm 0.3 \pm 0.5) \times 10^{-4}$
$B^0 \rightarrow J/\psi K^0(K_L)$	$(6.8 \pm 0.8 \pm 0.8) \times 10^{-4}$
$B^0 \rightarrow J/\psi K^0(K_S \rightarrow \pi^0 \pi^0)$	$(9.6 \pm 1.5 \pm 0.7) \times 10^{-4}$
$B^0 \rightarrow J/\psi K^0(K_S \rightarrow \pi^+ \pi^-)$	$(8.5 \pm 0.5 \pm 0.6) \times 10^{-4}$
$B^0 \rightarrow J/\psi K^0(All)$	$(8.3 \pm 0.4 \pm 0.5) \times 10^{-4}$
$B^0 \rightarrow \chi_{c1} K^{*0}$	$(4.8 \pm 1.4 \pm 0.9) \times 10^{-4}$
$B^0 \rightarrow \chi_{c1} K^0$	$(5.4 \pm 1.4 \pm 1.1) \times 10^{-4}$
$B^+ \rightarrow \chi_{c1} K^+$	$(7.5 \pm 0.8 \pm 0.8) \times 10^{-4}$
$B^+ \rightarrow \psi(2S) K^+$	$(6.3 \pm 0.5 \pm 0.8) \times 10^{-4}$
$B^0 \rightarrow \psi(2S) K^0$	$(6.8 \pm 1.0 \pm 1.1) \times 10^{-4}$

BABAR determinations from fits to the angular distributions are

$$\begin{aligned}
|A_{\perp}|^2 &= 0.160 \pm 0.032 \pm 0.014, \\
|A_{\parallel}|^2 &= 0.243 \pm 0.034 \pm 0.017, \\
|A_0|^2 &= 0.597 \pm 0.028 \pm 0.02, \\
\phi_{\perp} &= \arg\left(\frac{A_{\perp}}{A_0}\right) = -0.17 \pm 0.16 \pm 0.07, \\
\phi_{\parallel} &= \arg\left(\frac{A_{\parallel}}{A_0}\right) = 2.50 \pm 0.20 \pm 0.08.
\end{aligned}$$

In the factorization hypothesis the relative phases of the three amplitudes should be 0 or π . The measurement of ϕ_{\parallel} shows a deviation from π of three standard deviations, giving indication of the presence of final-state interactions.

The dilution factor for the measurement of $\sin 2\beta$ in this channel is determined from the relative CP -odd contribution:

$$D = 1 - 2|A_{\perp}|^2 = 0.68 \pm 0.10.$$

4 Open Charm decays

B mesons decays to three-body final states through the chain $b \rightarrow c\bar{c}s$ have been studied by BABAR. The current experimental results on two-body decays $B \rightarrow D_s X$, $(cc)X$, $\Lambda_c X$, $\Xi_c X$ from

ALEPH [9] and CLEO [10] give a contribution to a $b \rightarrow c\bar{c}s$ branching fraction [11] lower than expected from the theoretical extrapolation from the semileptonic branching ratio. This may be an indication that the three-body decays could give a non-negligible contribution to the total $b \rightarrow c\bar{c}s$ branching fraction. BABAR results on $B \rightarrow D^*D^{(*)}K$ modes are the following:

$$\begin{aligned}\mathcal{B}(B^0 \rightarrow D^{*+}D^0K^+) &= (0.28 \pm 0.07 \pm 0.05) \times 10^{-2}, \\ \mathcal{B}(B^0 \rightarrow D^{*+}D^{*0}K^+) &= (0.68 \pm 0.17 \pm 0.17) \times 10^{-2}, \\ \mathcal{B}(B^+ \rightarrow D^{*+}D^{*-}K^+) &= (0.34 \pm 0.16 \pm 0.11) \times 10^{-2}.\end{aligned}$$

The last mode is the first experimental evidence of a color-suppressed mode other than $B \rightarrow (\text{charmonium})X$.

The decays $B \rightarrow D^{*+}D^{*-}$ provide an interesting Cabibbo-suppressed $b \rightarrow c\bar{c}d$ process that could provide, with enough events, a determination of $\sin 2\beta$ independent on the mode $J/\psi K^0$. The determination of $\sin 2\beta$ would require particular care in the subtraction of penguin contributions, which could be non-negligible. The theoretical estimate for the branching fraction of this mode is

$$\mathcal{B}(B \rightarrow D^{(*)}\bar{D}^{(*)}) \approx \left(\frac{f_{D^*}}{f_{D_s^*}} \right) \tan \theta_c \mathcal{B}(B \rightarrow D_s^{(*)}\bar{D}^{(*)}) \approx 0.1\%.$$

BABAR measures

$$Br(B^0 \rightarrow D^{*+}D^{*-}) = (8.0 \pm 1.6 \pm 1.2) \times 10^{-4}.$$

5 Two-body decays

In the Standard Model the study of charmless two-body B decays with final states $\pi\pi$ and $K\pi$ allows us to determine, with sufficient events, through a time dependent CP asymmetry study, the value of $\sin 2\alpha$. Unlike the $\sin 2\beta$ modes, these decays have a penguin contribution that is non-negligible compared to the Cabibbo-suppressed tree decay, and whose phase differs from the tree diagram phase. The parameter $\sin 2\alpha$ can be extracted from the raw CP-violating asymmetry for $B^0 \rightarrow \pi^+\pi^-$ by applying a correction that takes into account the penguin pollution [13]. This correction depends on all the other $B \rightarrow \pi\pi$ amplitudes and, in particular, both $B^0 \rightarrow \pi^0\pi^0$ and $\bar{B}^0 \rightarrow \pi^0\pi^0$ need to be measured.

Particle identification with the DIRC is of fundamental importance to correctly discriminate pions from kaon background. Continuum events are rejected on the basis of event shape variables that are combined into a Fisher discriminant. The branching fractions are determined from an unbinned likelihood fit that combines kinematical information with the Cherenkov angle measured in the DIRC. The probability distribution functions for the Cherenkov angle have been determined from the control sample $D^{*+} \rightarrow D^0\pi^+ \rightarrow (K^-\pi^+)\pi^+$ in real data, and for the kinematical variables from the off-resonance data and the $(\Delta E, m_{ES})$ sidebands. The results for all two-body modes are summarized in the Tables 3, 4 and 5.

The decay channels for the B^\pm and $B^0 \rightarrow K^+\pi^-$ are self-tagging, in the sense that the flavor of the b quark in the B meson can be determined from the charge of the particles in the final state. For those decays we have determined the direct CP asymmetries reported in Table 6.

The decays $B \rightarrow \phi K$ and $B \rightarrow \phi K^*$ are dominated by the gluonic penguin diagrams for $b \rightarrow s\bar{s}s$, and provide potentially an independent determination of $\sin 2\beta$ and could show direct CP violation effects.

The ϕ is reconstructed in the decay mode $\phi \rightarrow K^+K^-$, where both final state kaons are identified in the DIRC and must have an invariant mass within ± 30 MeV of the ϕ mass. BABAR results for $B \rightarrow \phi K^{(*)}$ and $\phi\pi$ are reported in Table 7.

Table 3: $B^0 \rightarrow h^+ h^-$ branching fractions.

Decay Mode	Branching Fraction	Yield	Significance
$B^0 \rightarrow K^+ \pi^-$	$(16.7 \pm 1.6^{+1.2}_{-1.7}) \times 10^{-6}$	$169 \pm 17^{+12}_{-17}$	15.8σ
$B^0 \rightarrow \pi^+ \pi^-$	$(4.1 \pm 1.0 \pm 0.7) \times 10^{-6}$	$41 \pm 10 \pm 7$	4.7σ
$B^0 \rightarrow K^+ K^-$	$< 2.5 \times 10^{-6}$ (90%C.L.)	$8.2^{+7.8}_{-6.4} \pm 3.3$	1.3σ

Table 4: $B^+ \rightarrow \pi^0 h^+$ branching fractions.

Decay Mode	Branching Fraction	Yield	Significance
$B^+ \rightarrow \pi^0 \pi^+$	$(5.1^{+2.0}_{-1.8} \pm 0.8) \times 10^{-6}$	37^{+15}_{-13}	3.4σ
$B^+ \rightarrow \pi^0 K^+$	$(10.8^{+2.1}_{-1.9} \pm 1.0) \times 10^{-6}$	75^{+14}_{-13}	8.0σ

Table 5: $B^+ \rightarrow K^0 h^+$ and $B^0 \rightarrow K^0 \pi^0$ branching fractions.

Decay Mode	Branching Fraction	Yield	Significance
$B^+ \rightarrow K^0 \pi^+$	$(18.2^{+3.3}_{-3.0} \pm 1.6) \times 10^{-6}$	59^{+11}_{-10}	9.8σ
$B^+ \rightarrow K^0 K^+$	$< 2.6 \times 10^{-6}$ (90% C.L.)	0 (< 8 , 90%C.L.)	0σ
$B^0 \rightarrow K^0 \pi^0$	$(17.9^{+6.8}_{-5.8} \pm 1.1) \times 10^{-6}$	$17.99^{+6.8}_{-5.8}$	4.5σ

Table 6: Direct CP asymmetries.

Decay Mode	CP Asymmetry	90% C.L. interval
$B^0 \rightarrow K^+ \pi^-$	$-0.19 \pm 0.10 \pm 0.03$	$[-0.35, +0.03]$
$B^+ \rightarrow K^+ \pi^0$	$0.00 \pm 0.18 \pm 0.04$	$[-0.30, +0.30]$
$B^- \rightarrow K^0 \pi^-$	$-0.21 \pm 0.18 \pm 0.03$	$[-0.51, +0.09]$

Table 7: $B^+ \rightarrow \phi K^{(*)}, \phi\pi$ branching fractions.

Decay Mode	Decay Fraction	Yield	Significance
$B^+ \rightarrow \phi K^+$	$(7.7_{-1.4}^{+1.6} \pm 0.8) \times 10^{-6}$	$31.4_{-5.9}^{+6.7}$	10.5σ
$B^+ \rightarrow \phi\pi^+$	$< 1.4 \times 10^{-6} (90\% C.L.)$	$0.9_{-0.9}^{+2.1}$	0.6σ
$B^+ \rightarrow \phi K^{*+}$	$(9.7_{-3.4}^{+4.2} \pm 1.3) \times 10^{-6}$	—	4.5σ
$B^+ \rightarrow \phi K^{*+}(K^+)$	$(12.8_{-6.1}^{+7.7} \pm 3.2) \times 10^{-6}$	$7.1_{-3.4}^{+4.3}$	2.7σ
$B^+ \rightarrow \phi K^{*+}(K^0)$	$(8.0_{-3.7}^{+5.0} \pm 1.3) \times 10^{-6}$	$4.4_{-2.0}^{+2.7}$	3.6σ
$B^0 \rightarrow \phi K^{*0}$	$(8.6_{-2.4}^{+2.8} \pm 1.1) \times 10^{-6}$	$16.9_{-4.7}^{+5.5}$	6.6σ
$B^0 \rightarrow \phi K^0$	$(8.1_{-2.5}^{+3.1} \pm 0.8) \times 10^{-6}$	$10.8_{-3.3}^{+4.1}$	6.4σ

6 Quasi-two body decays

A number of quasi-two-body and three-body decay modes have been studied by BABAR. Of particular interest, a three-body Dalitz analysis of $B \rightarrow \rho\pi$ decays allows a determination of $\sin 2\alpha$ and, at the same time, the strong phases of the tree and penguin diagrams [12]. BABAR results for various modes are summarized in Table 8.

7 Radiative penguin decays

The decay $B \rightarrow K^*\gamma$ is dominated by the electromagnetic penguin diagram. The main contribution comes from the diagram involving a t quark in the loop, so it is sensitive to the CKM elements V_{ts} and V_{td} . The Standard Model prediction for the direct CP asymmetry in $B \rightarrow K^*\gamma$ is below 1%.

In the presence of new physics beyond the Standard Model, the electromagnetic penguin could be enhanced by charged Higgs or supersymmetric particles, increasing the branching ratio. The direct CP asymmetry could become measurable at BABAR.

The selection of $B^0 \rightarrow K^{*0}\gamma$ events is based on identification of a photon in the calorimeter, not coming from the decay of a π^0 or η , and reconstruction of K^{*0} candidates decaying to $K^+\pi^-$. The rejection of the non-resonant $e^+e^- \rightarrow q\bar{q}$ background is performed on the basis of the angle formed by the photon and the thrust axis of all particles in the event except those belonging to the $K^*\gamma$ candidate. BABAR determines the following branching ratio:

$$\mathcal{B}(B^0 \rightarrow K^{*0}\gamma) = (4.39 \pm 0.41 \pm 0.27) \times 10^{-5}.$$

The sample is composed of 72 ± 9 $B^0 \rightarrow K^{*0}\gamma \rightarrow K^+\pi^-\gamma$ events and 67.2 ± 9.1 $\bar{B}^0 \rightarrow \bar{K}^{*0}\gamma \rightarrow K^+\pi^-\gamma$ events. The direct CP asymmetry has been determined to be

$$A_{CP}(B^0 \rightarrow K^{*0}\gamma) = -0.035 \pm 0.094 \pm 0.022.$$

Table 8: Quasi-two-body and three-body branching fractions.

Decay Mode	Branching Fraction
$B^+ \rightarrow \omega h^+$	$< 24 \times 10^{-6} (90\% \text{ C.L.})$
$B^0 \rightarrow \omega K^0$	$< 14 \times 10^{-6} (90\% \text{ C.L.})$
$B^+ \rightarrow \eta' K^+$	$(62 \pm 18 \pm 8) \times 10^{-6}$
$B^0 \rightarrow \eta' K^0$	$< 112 \times 10^{-6} (90\% \text{ C.L.})$
$B^+ \rightarrow K^{*0} \pi^+$	$< 28 \times 10^{-6} (90\% \text{ C.L.})$
$B^+ \rightarrow \rho^0 K^+$	$< 39 \times 10^{-6} (90\% \text{ C.L.})$
$B^+ \rightarrow \rho^0 \pi^+$	$< 39 \times 10^{-6} (90\% \text{ C.L.})$
$B^+ \rightarrow K^+ \pi^+ \pi^-$	$< 54 \times 10^{-6} (90\% \text{ C.L.})$
$B^+ \rightarrow \pi^+ \pi^+ \pi^-$	$< 22 \times 10^{-6} (90\% \text{ C.L.})$
$B^0 \rightarrow \rho^\pm \pi^\mp$	$(49 \pm 13^{+6}_{-5}) \times 10^{-6}$

8 Conclusions

BABAR has recorded 22.6 million BB events in the period from November 1999 to October 2000. Analyses hadronic B decays and the study of rare processes in BABAR have shown first evidence of charmonium production in continuum and have provided precise determinations of branching fractions of B to exclusive and inclusive charmonium final states, including the first observation of the decay $B^0 \rightarrow \chi_{c1} K^{*0}$. BABAR has observed the color-suppressed decay $B^+ \rightarrow D^{*+} D^{*-} K^+$, and studied two-body charmless decays that will provide, with larger data samples, a measurement of $\sin 2\alpha$. The radiative penguin decay $B^0 \rightarrow K^{*0} \gamma$ has been studied and a first measurement of the CP asymmetry in that channel has been performed.

Many measurements are still dominated by statistical uncertainty, and more events will allow the reduction of the errors and access to more rare channels.

Acknowledgments

We are grateful for the extraordinary contributions of our PEP-II colleagues in achieving the excellent luminosity and machine conditions that have made this work possible. The collaborating institutions wish to thank SLAC for its support and the kind hospitality extended to them. This work is supported by the US Department of Energy and National Science Foundation, the Natural Sciences and Engineering Research Council (Canada), Institute of High Energy Physics (China), the Commissariat à l'Energie Atomique and Institut National de Physique Nucléaire et de Physique des Particules (France), the Bundesministerium für Bildung und Forschung (Germany), the Istituto Nazionale di Fisica Nucleare (Italy), the Research Council of Norway, the Ministry of Science and Technology of the Russian Federation, and the Particle Physics and Astronomy Research Council (United Kingdom). Individuals have received support from the Swiss National Science Founda-

tion, the A. P. Sloan Foundation, the Research Corporation, and the Alexander von Humboldt Foundation.

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